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LOWER LIMB JOINT KINETICS IN THE BLOCK PHASE OF ATHLETIC SPRINTING: RELATIONSHIP WITH PERFORMANCE CHARACTERISTICS.

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The aim of this study was to investigate the relationship between internal and external kinetics in the block phase of athletic sprinting. Ten male sprinters (100 m PB 10.50 ± 0.27 s) performed five to six maximal effort block starts. External force (10000 Hz) and 3D kinematics (250 Hz) were collected and internal kinetics at the ankle, knee and hip joint were calculated using inverse dynamics. Results indicated no significant associations between joint kinetic variables and block performance, although horizontal force production in the front and rear block was significantly related to kinetic data at the front knee and ankle, and rear hip and ankle, respectively. The present study expands current knowledge of force production in the block phase and highlights that no joint is independently able to significantly determine block performance.

KEY WORDS: Sprint start, sprint running, sprint biomechanics

INTRODUCTION: In the short sprint events, performance of the starting block phase can be of critical importance to the outcome of the race as an athlete attempts to maximise centre of mass acceleration from the stationary 'set' position. This acceleration of the centre of mass is influenced by the nature of external force application in the starting blocks and the underpinning joint kinetics responsible for segment motion during the block phase.

Recently, utilising force instrumented starting blocks, Brazil et al. (2015) found that superior performance in the block phase was associated with the magnitude of force applied to the front block and the technical orientation of force applied to the rear block. However, the strongest relationship with performance was found for total average horizontal force ($r = 0.98$, $P < 0.05$), indicating the importance of maximising total horizontal force production. Although external kinetic analyses (e.g. Brazil et al., 2015; Otsuka et al., 2014; Willwacher, Herrmann, Heinrich, & Brüggemann, 2013) provide valuable insight into block phase performance, calculating joint kinetics allows for an increased understanding of the causes of segment motion responsible for centre of mass acceleration. Due to methodological challenges associated with collecting block forces this has rarely been achieved. However, Mero, Kuitunen, Harland, Kyröläinen, and Komi, (2006) were able to calculate lower limb joint kinetic data by mounting starting blocks onto separate force platforms and combining with two-dimensional video data. External forces were assigned to the distal end of the foot segment at the metatarsophalangeal (MTP) joint. To the authors' knowledge, no study to date has calculated lower limb joint kinetic data using 3D motion capture and instrumented starting blocks, or investigated the relationships between joint moment and power data, and external force characteristics in the block phase.

The aim of this study was to investigate how performance and force production in the block phase is associated with lower limb joint moment and power, in order to further understand block phase performance and the application of force to the starting blocks. It was hypothesised that stronger relationships with block performance would be found for front leg joint kinetic data, given the much stronger relationship between front block average horizontal force and block performance (Brazil et al., 2015).

METHODS: Ten male sprinters (24 ± 4 years, 1.78 ± 0.04 m, 76.67 ± 2.74 kg) with 100 m PB ranging from 10.10-10.96 s (10.50 ± 0.27 s) gave written informed consent to participate in

this study following institutional ethical approval. Each sprinter performed five to six maximal 10 m sprints from blocks and three dimensional external force and kinematic data were collected during the block phase. For analysis, the block phase was separated into two sub-phases: rear (rear leg) and front (front leg). Each sub-phase was defined between block start (earliest detection in which the first derivative of either the front or rear resultant force-time curve exceeded $500 \text{ N}\cdot\text{s}^{-1}$) and the end of the respective sub-phase (resultant force $< 50 \text{ N}$). Kinematic data were collected using a 15 camera motion capture system (Vicon, Oxford Metrics, UK, 250 Hz), calibrated to residual errors of $< 0.3 \text{ mm}$ using a 240 mm calibration wand. Retro-reflective markers (14 mm) were attached bilaterally to the: iliac crest, posterior superior iliac spine, anterior superior iliac spine, lateral and medial femoral epicondyles, lateral and medial malleoli, first and fifth metatarsal heads, calcaneus, and head of the second toe. Technical clusters comprising four markers were attached towards the distal end of the thigh and shank segments. External force data (10000 Hz, post processed to 1000 Hz) were collected from each block using custom force instrumented blocks (Willwacher et al., 2013) comprising four piezoelectric load cells (Kistler, Winterthur, Switzerland) mounted onto separate base units which were orientated 50° relative to the horizontal. All sprinters were instructed to have their foot in contact only with the blocks and not with the ground. Force signals were low-pass filtered (4th order Butterworth, 120 Hz cut-off) prior to analysis. Synchronisation of external force and kinematic data was achieved through a known voltage rise present in both datasets, triggered by the block software prior to the starting sound.

Processing of kinematic and kinetic data was performed using Visual 3D (C-Motion Inc, Germantown, USA). Raw marker coordinates were low-pass filtered (4th order Butterworth) at a cut-off of 12 Hz determined using residual analysis. A static calibration was used to define the local coordinate system of nine lower limb segments (pelvis and bilateral thigh, shank, foot and toe). For each segment the x-axis pointed to the right, y-axis pointed forwards and z-axis upwards. Newton-Euler inverse dynamics procedures were used to calculate resultant joint moment at the ankle, knee and hip joints and were resolved in the proximal segments coordinate system. Only x-axis (flexion-extension) data were reported due to the predominant sagittal nature of sprinting. Based on the work by Mero et al. (2006) a virtual landmark that projected the MTP joint centre onto the surface of the block was used to define centre of pressure for the front and rear leg. Joint power was calculated as the product of joint moment and angular velocity. Average extensor moment and average positive extensor power for the front and rear ankle, knee and hip joint were calculated and used for further analysis.

Average rear, front and total (front + rear) block horizontal force (F_Y) were calculated from the respective force-time signal during the block phase. To quantify block performance, average horizontal power (calculated by multiplying the total force- and velocity-time signals) was normalised to a dimensionless value (Bezodis, Salo, & Trewartha, 2010) to obtain normalised average horizontal power (NAHP).

All data were confirmed to be normally distributed (Shapiro-Wilk $P > 0.05$) prior to analysis. Pearson's product-moment correlations were calculated to determine the relationship between joint kinetic data, force characteristics (rear or front F_Y) and NAHP. Correlation strength was interpreted using the convention recommended by Hopkins (2016): trivial (< 0.1) small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7) very large (0.7-0.9) and practically perfect (0.9-1.0). An alpha level of $P < 0.05$ defined a statistically significant correlation.

RESULTS: Mean \pm SD average rear F_Y , front F_Y , total F_Y , and NAHP were $5.70 \pm 0.68 \text{ N/kg}$, $5.99 \pm 0.70 \text{ N/kg}$, $9.09 \pm 0.52 \text{ N/kg}$ and 0.52 ± 0.05 , respectively. A practically perfect correlation was observed between total F_Y and NAHP ($r = 0.98$, $P < 0.05$). Although no significant correlation was found between joint kinetic data and block performance (Table 1), moderate-large correlations were observed for front ankle, knee and hip moment ($r = 0.59$, 0.51 and 0.47 , respectively), and front knee power ($r = 0.54$). Rear F_Y was significantly associated with rear ankle and hip moment and power, whilst front ankle moment and front knee moment and power were significantly related to front F_Y (Table 1).

Table 1. Correlations (r values) between internal and external kinetic variables

Variable	Rear F _Y	Front F _Y	NAHP
Rear ankle moment	0.88*		-0.13
Rear knee moment	-0.04		-0.04
Rear hip moment	0.87*		-0.22
Rear ankle power	0.64*		0.14
Rear knee power	-0.05		-0.04
Rear hip power	0.84*		-0.26
Front ankle moment		0.82*	0.59
Front knee moment		0.81*	0.51
Front hip moment		0.58	0.47
Front ankle power		0.16	0.18
Front knee power		0.81*	0.54
Front hip power		0.27	0.28
Rear F _Y			0.06
Front F _Y			0.80*
Total F _Y			0.98*

*denotes statistically significant ($P < 0.05$) correlation.

DISCUSSION:

The aim of this study was to investigate how block performance and force production in the block phase were related to lower limb moment and power, in order to further understand the discriminating factors between levels of block performance. Although no significant relationships were observed between block performance and joint kinetic data, results provided novel insight into the lower limb contribution towards horizontal force production in the starting blocks.

The practically perfect relationship between total F_Y and NAHP (Table 1), reaffirmed findings by Brazil et al. (2015) that maximising total average horizontal force is a key strategy for superior block performance. Given that horizontal force production is vital for block performance, it was of interest in the current study to understand whether kinetic data at the ankle, knee, or hip joint was related to front and rear F_Y. For the rear block, ankle and hip moment and power were significantly related to rear F_Y ($r = 0.64$ - 0.88 , $P < 0.05$, Table 1). As low extensor moments have been previously observed at the rear knee (Mero et al., 2006), it is unsurprising that rear F_Y possessed a trivial relationship with rear knee moment, and supported the large role of the ankle and hip joint in generating force in the rear block. With respect to the front block, front ankle and knee moment were significantly associated with front F_Y, whilst a non-significant, large correlation was found with front hip moment (Table 1). From the moment data, it is difficult to elucidate a specific joint that explained differences in front block horizontal force. However, when considering power data, only front knee power was significantly associated with front F_Y ($r = 0.81$, $P < 0.05$, Table 1). Thus, although all lower limb moments were related to front F_Y, it was the ability to organise powerful extension at the front knee joint that was found to be significantly related to the magnitude of horizontal force applied to the front block.

Trivial to small relationships ($r = -0.26$ - 0.14 , $P > 0.05$, Table 1) were found between rear leg joint kinetic variables and NAHP, whilst some moderate to large relationships ($r = 0.47$ - 0.59 , $P > 0.05$, Table 1) were found in the front leg, permitting the current hypothesis to be accepted. Again, relationships between front ankle, knee and hip moment and NAHP were of comparable magnitude, and only when looking at power data were clear differences between joints observed (Table 1). The large correlation between front knee power and NAHP ($r = 0.54$, $P > 0.05$, Table 1), supported by the significant association between front knee power and front F_Y indicated a trend towards the ability to generate power at the front knee being a key characteristic for starting block performance. However, the absence of significant relationships between front leg power data and NAHP, and similarity in correlation strength between front leg joint moments and NAHP (Table 1) suggested that block performance

could not be attributed solely to differences at one joint, and that optimally coordinating powerful leg extension may be of more importance for superior block performance.

The results of this study have practical implications for physical and technical training for the starting block phase. Although rear F_Y was not related to performance in this study or Brazil et al. (2015), large forces are still observed in the rear block (Brazil et al., 2015; Otsuka et al., 2014; Willwacher et al., 2013). The current data would suggest that the magnitude of rear F_Y is related to the strength and power of the hip and ankle extensor musculature and so optimising the set position to increase the contribution of these muscle groups may be a technical aspect for coaches to focus on. With respect to the front leg, improving overall strength and power capacity should be a focus of strength training programmes, although an emphasis on exercises that promote triple extension of the ankle, knee and hip joints with high power output at the knee joint may result in the greatest adaptations that can positively impact starting block performance.

CONCLUSION: Results indicated that block performance was not significantly associated with lower limb joint moment and power, although a trend towards the front knee being a key factor for block performance was identified. Ultimately, to maximise block performance it appears that coordinating powerful extension of the lower limb is more important than maximising the power of any one joint. The study provided novel insight into the lower limb joints that were related to horizontal force production, namely the rear ankle and hip joints and front ankle and knee joints. Findings contribute to the continued understanding of the starting block phase in sprinting and may help guide strength training programmes for enhancing block performance.

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